Evaluation of Bank Storage Along the Columbia River Between Richland and China Bar, Washington

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storage and its effect on the flow of the river along one segment of the Columbia River.

LOCATION AND CHARACTERISTICS OF THE AREA

The Columbia River flows through the Pasco Basin in a locally broadened segment of its characteristic gorge. This locally broadened segment includes 90 miles of the river between its passages through mountain ridges in Sentinel and Wallula Gaps (fig. 1) Its

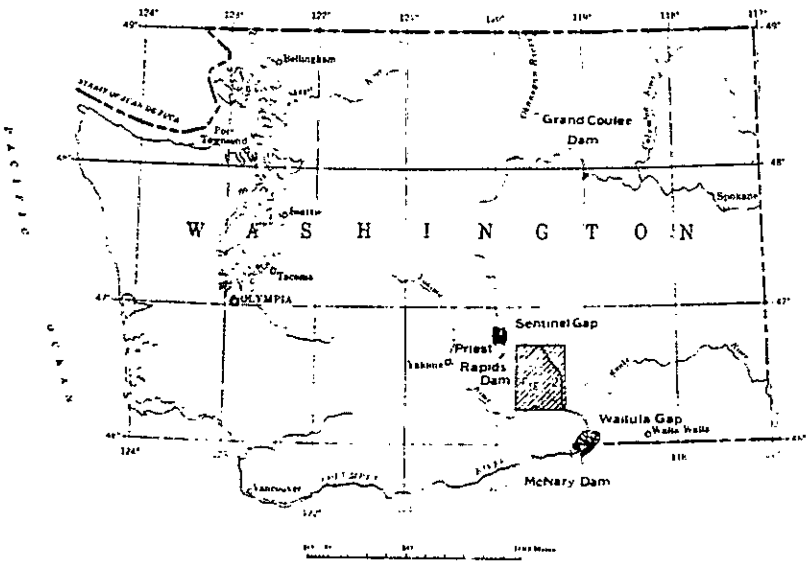

FIGURE 1.—Index map showing the location of the area covered by figure 2.

topography is a diverse mixture of flood plains, terraces, river bluffs, and low plateaus with some mountain ridges (fig. 2). McNary Dam, 15 miles downstream from Wallula Gap and 42 miles downstream from Richland, impounds the river to an altitude of about 340 feet, and the slack water of the reservoir reaches upstream about halfway through the Pasco Basin to a point several miles above Richland. The Priest Rapids damsite lies at the north foot of Umtanum Ridge, about 4 miles upstream from China Bar which is at the northwest edge of the Hanford Reservation. Thus, the reach of river treated in this report extends from the slack water of the McNary Reservoir to the bedrock channel near Priest Rapids. In this 50-mile segment the river descends evenly from an average low-water level of about 392 feet at China Bar to the 340-foot level of the McNary Reservoir, except for a drop of about 8 feet in the ¼-mile length of Coyote Rapids. The low-water level at Richland prior to closure c cNary Dam was about 326 feet, as shown on figure 3.

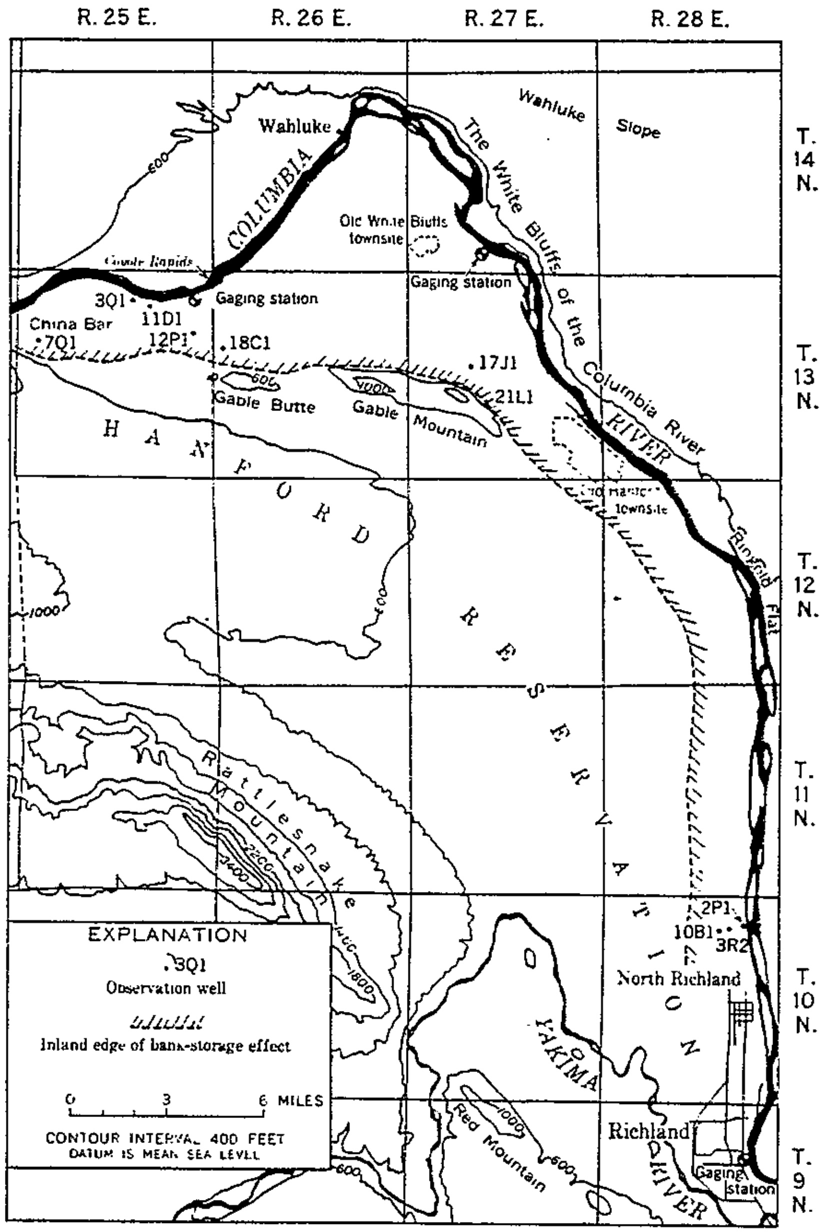

FIGURE 2.—Map showing the location of the observation wells and the zone of observed bank-storage effect along the Columbia River between Richland and China Bar on the Hanford Reservation, Wash.

The Pasco-Kennewick area, just downstream from Richland, and the Hanford Reservation, upstream from Richland, are two large areas of terraced land. The altitudes of the terraces range from about 340 feet at reservoir level to about 700 feet on the high terraces in the northwestern part of the Hanford Reservation.

GENERAL GEOLOGIC CHARACTERISTICS

The Columbia River basalt of Miocene and Pliocene(?) age is a layered sequence of lava flows several thousand feet thick. It forms the bedrock of the area and is exposed in the ridges that bound the Pasco Basin and in a few knobs, such as Gable Mountain and Gable Butte, which project above terrace lands. The basalt is permeable mainly along the contact zones between some of the lava flows. The overall permeability of the basalt is much less than that of the coarse-grained members of the unconsolidated deposits which overlie it.

In the downwarped syncline beneath the Pasco Basin the basalt is overlain by the Ringold formation, which is a lacustrine deposit composed predominantly of silt. The Ringold also contains much sand, some clay, and one prominent member of weakly consolidated gravel and sand that commonly is called "the conglomerate." The Ringold formation in places lies on the basalt at an altitude in general near sea level and extends up to about 1,000 feet. The 600 feet of strata exposed above the level of the Columbia River are horizontal or nearly horizontal, but some of the lowest strata, now below river level at The White Bluffs, may have been folded and tilted in the last deformation of the basalt bedrock. The conglomerate member of the Ringold formation consists of gravel and sand and was deposited in a trainlike band about 10 miles wide across the lacustrine basin of deposition from near Sentinel Gap to Wallula Gap. The member is about 160 feet thick; throughout much of the Pasco Basin it lies between altitudes of 290 and 450 feet. The conglomerate is not present in The White Bluffs northward from Ringold Flat to Wahluke.

A mantle of glaciofluviatile and fluviatile deposits overlies the eroded surface of the Ringold formation throughout the lowlands between The White Bluffs and the several mountain-sized ridges, collectively known as the Yakima Ridges, and throughout the Pasco-Kennewick area southeastward to Wallula Gap. The deposits range in thickness from 20 to 100 feet and consist largely of gravel but contain some sand beds. The gravel is mostly of granule and pebble size but in places includes many cobbles and some boulders. In a few places it includes thick beds consisting almost entirely of boulders. In other p[illegible]es, especially in the upper part of the deposit along

embayments in the mountain fronts and in areas sheltered from erosion, silt lenses and other fine-grained deposits predominate. The glaciofluviatile and fluviatile deposits occur as a deep mantle upward from the river level to an altitude of about 700 feet and as a thinner mantle to about 1,150 feet. They lie above the low-water level of the riverbed in all but a few places and above the natural level of the water table in large parts of the reservation and the Pasco-Kennewick area.

The most important aspect of the geology as related to the problem of bank storage is the position of the irregular but nearly horizontal contact between the Ringold formation and the overlying more permeable glaciofluviatile and fluviatile deposits. Along the right bank of the river near North Richland this contact lies at an altitude of about 340 feet (very near to the average level of the reservoir) and about 10 to 20 feet above the average river level along most of the right bank upstream from North Richland to China Bar. In the vicinity of the old Hanford townsite and the broad bench just downstream from China Bar, the contact lies below the average river level. The ground-water flow toward the river at low-water stages is largely in the Ringold formation, but the bank storage occupies a vertical zone lying both in the Ringold formation and in the glaciofluviatile deposits.

THE BANK-STORAGE EFFECT

ZONE OF INFLUENCE OF RIVER STAGE

Water levels in wells within a zone along about 50 miles of the right bank of the Columbia fluctuate with the stage of the river. They fluctuate in marked contrast with water levels in wells in other parts of the reservation, where seasonal changes in water level are insignificant. In general, fluctuations are greatest near the river and decrease in magnitude with distance from the river. The extent of the zone in which ground-water levels fluctuate in response to river stages is shown in figure 2. The observed water-table fluctuations range in height from 2.9 to 19.3 feet (figs. 3–5) and average 9.4 feet over an area of about 100 square miles.

The wells whose hydrographs are shown in figures 3–5 are numbered according to the following system: The township and range form the first two numerals and are separated by a slash; the section gives the third numeral. The letter refers to the 40-acre tract by a successive order in which A is the northeastern, D is the northwestern, E is SW¼NW¼, M is NW¼SW¼, N is the southwestern, and R is the southeastern. The letters I and O are omitted. The final numeral gives the order in which wells were numbered in th[illegible] 40-acre tract.

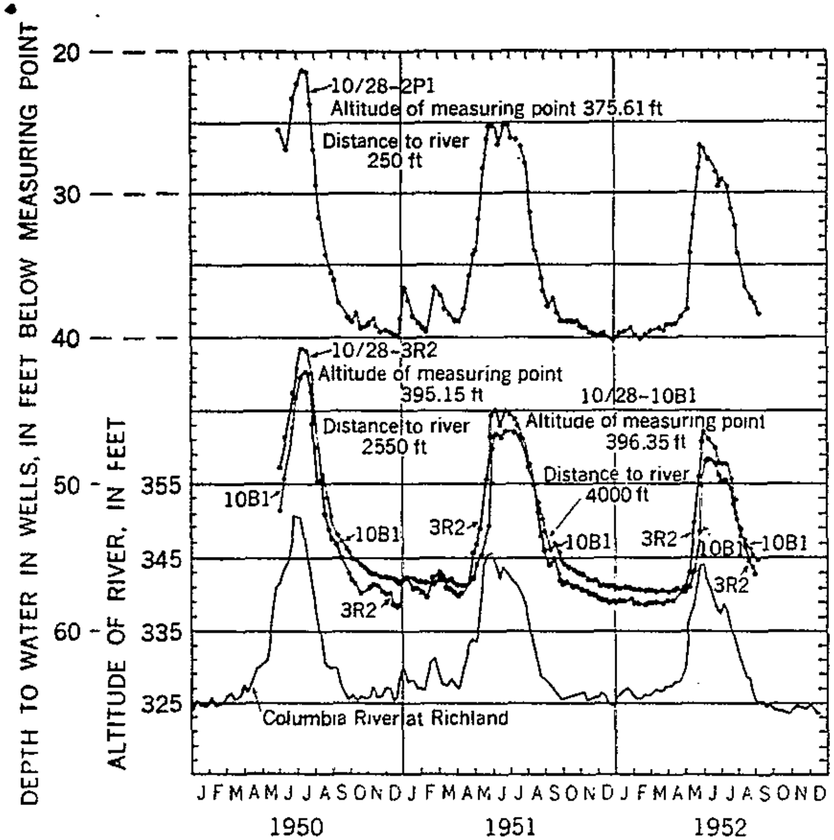

FIGURE 3.—Hydrographs of three wells in the southeastern part of the Hanford Reservation compared with the hydrograph of the Columbia River at Richland, Wash.

MANNER OF OCCURRENCE

The bank storage is a direct result of the seasonal fluctuations of river stage. When the river is at low stage, the water table lies mainly within the Ringold formation and slopes about 5 feet per mile toward the river. At that time, the flow of ground water into the river is small. As the river begins to rise in flood, at the start of the average 45-day period of increasing flow, the gradient of the water table toward the river is lessened and ground-water flow into the river decreases. As the river continues to rise, the gradient of the water table near the river is reversed and, by direct contribution of water through the bed and banks, the stream feeds the ground-water reservoir. The water is stored in the ground-water reservoir beneath land adjacent to the river, thus depleting the flow of the river slightly during periods of rising stage. After the stage of the river has peaked and begun to decline, the gradient again is reversed, and the bank-stored ground

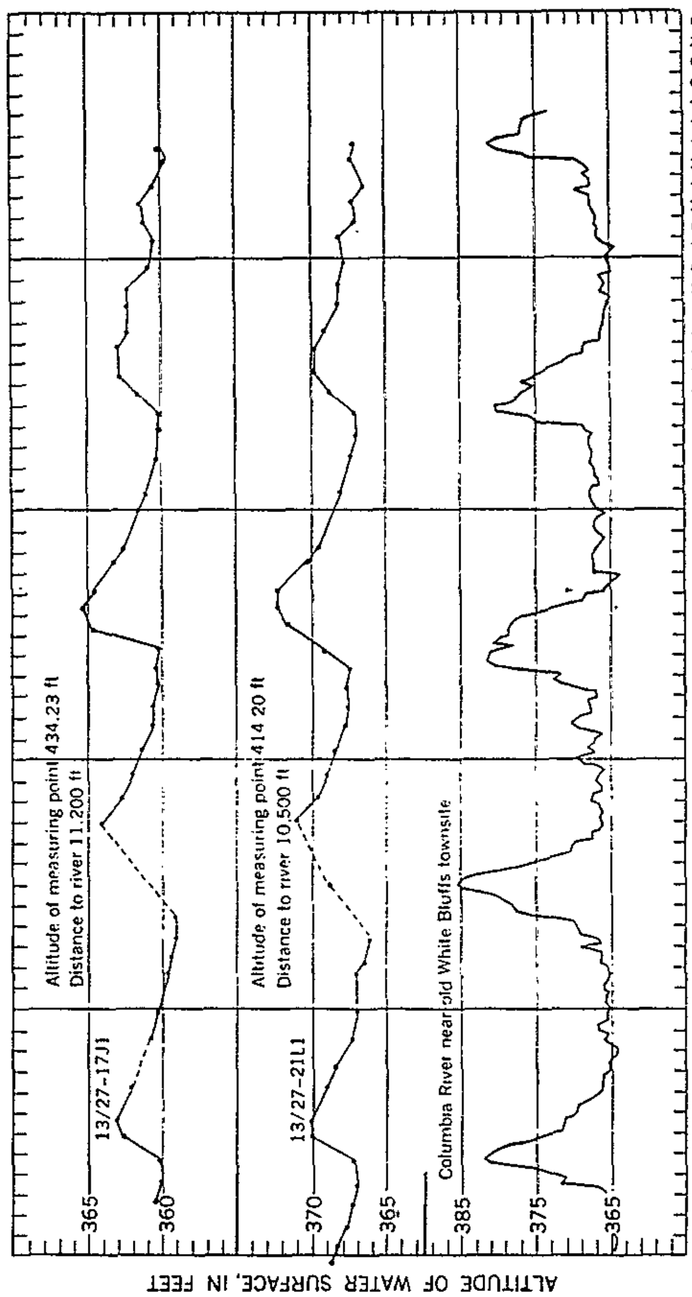

FIGURE 4.—Hydrograph of two wells northeast of Gable Mountain compared with the hydrograph of the Columbia River near old White Bluffs townsite, Washington.

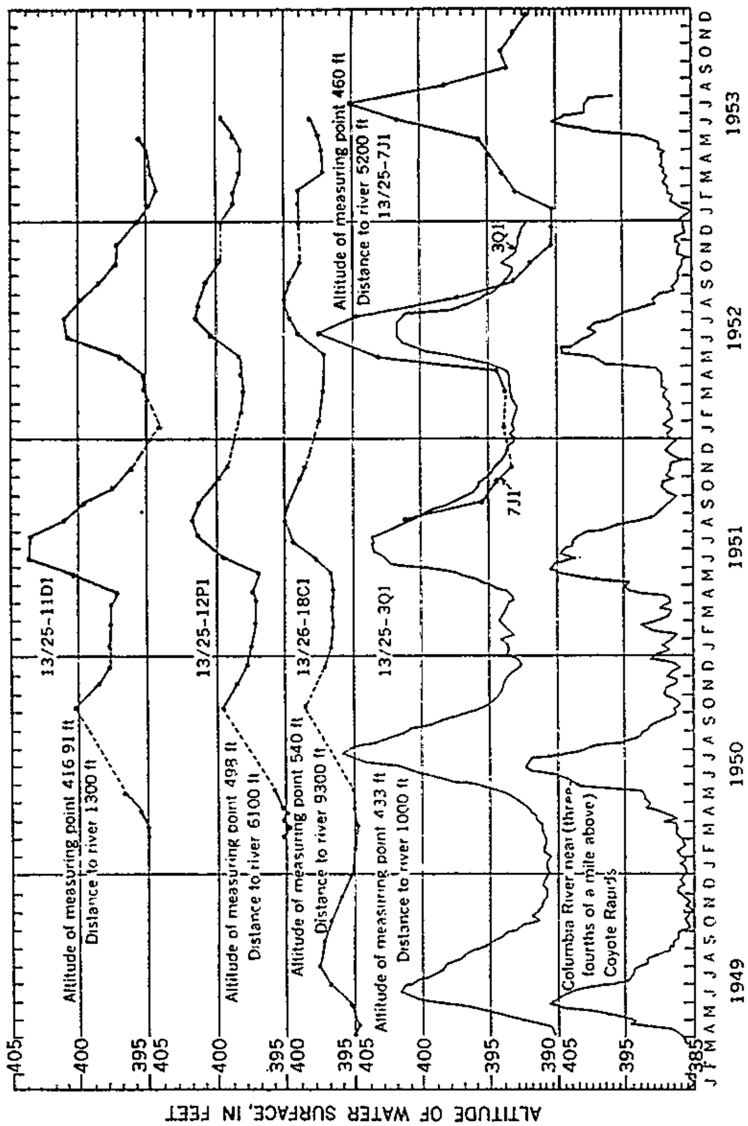

FIGURE 5.—Hydrographs of wells south and west of Coyote Rapids in the northwestern part of the Hanford Reservation compared with the hydrograph of the Columbia River near Coyote Rapids, Wash.

water percolates to the river until the normal average gradient toward the river is restored. During this period of draining, water levels within the bank-storage zone along the river decline for about 150 to 180 days.

This percolation into the bed and its complete direct return characterizes the bank-storage zone in all but a few places. The area inside the river bend near the old White Bluffs townsite has one variation from the normal pattern of direct-return percolation. The influent percolation along the upstream side of this large river bend can raise the water table sufficiently to cause some of the water to percolate eastward across the bend, escaping the zone of direct return and entering the river above the old Hanford townsite.

Radioactive tracers demonstrate that the bank-stored water has some downstream movement and that its return to the river is slightly oblique downstream rather than normal to the river's edge. However, this detail does not diminish the general directness of the infiltration and return of the bank storage.

GEOHYDROLOGIC DATA

Bank storage is confined to a mixed zone of conglomerate of the Ringold formation and the overlying glaciofluviatile and fluviatile deposits, except in a few places such as part of the old White Bluffs townsite area, which lies northeast of the train of conglomerate in the Ringold. There, during the high levels of ground water, the materials saturated are the silt and sand of the Ringold and the overlying glaciofluviatile and fluviatile deposits.

From several pumping tests and computations, the permeability of the conglomerate of the Ringold formation has been determined to range from 100 to 800 gpd (gallons per day) per square foot. As determined in two places on the reservation, its effective porosity is 11 percent.

The glaciofluviatile and fluviatile deposits are much more permeable than the conglomerate of the Ringold formation. Aquifer tests indicate that the permeability of these deposits ranges from about 16,000 to 60,000 gpd per square foot. Their effective porosity is about 20 percent. As about two-thirds of the water in bank storage is in the conglomerate of the Ringold formation (average permeability about 450 gpd per square foot) and the other third is in the overlying glaciofluviatile and fluviatile deposits (average permeability about 38,000 gpd per square foot), an overall average permeability of about 13,000 gpd per square foot can be assumed for the wedge of permeable materials that are saturated and dewatered during each annual flood cycle. In a similar manner, an average effective porosity of about 14 percent may be assumed for these materials.

By the end of the drain-back period, the water table has declined until it lies in the Ringold formation throughout most of the bank-storage zone. Hence, in computing an estimate of the normal amount of ground water percolating to the river during the low-water part of the year when there is little or no bank-storage contribution, the average permeability of the Ringold formation (450 gpd per square foot) is used. Computations employing Darcy's law indicate that the normal ground-water contribution to river flow at low-water stages would be equal to less than 1 percent of the water that accumulates in bank storage during the average 45-day period of rise in river stage.

The hydrographs given in figures 3 to 5 are typical of those of the observation wells in the zone of bank storage. Water levels of three wells north of North Richland rose and fell in close agreement with the level of the river, as observed at Richland (fig. 3). The average amplitude of the annual bank-storage rise decreases from about 16 feet in the well 250 feet from the river to about 12 feet in the well 4,000 feet from the river. Changes in ground-water levels lag slightly less than 1 week behind changes in river level, and the lag is only slightly greater in the well at 4,000 feet than in the well only 250 feet from the river.

The special type of fluctuation induced in ground-water levels near the inland edge of the bank-storage zone north of Gable Mountain is illustrated by the hydrographs of two wells in figure 4. The hydrographs show that the peak levels of ground water follow about 2 months behind those of the river nearby and that ground water rises to peak levels and declines to low levels at a slower rate than the river. These wells lie near the land edge of the area in which ground water moves across the circuitous bend at old White Bluffs. The length of the flood-time fluctuation of the water levels in these wells may represent ground water transmitted from the northwest rather than entirely bank storage.

In figure 5 the hydrographs of five wells show a greater lag and a decreasing amplitude of the annual bank-storage wave with progressively greater distance from the river. They also show a lesser altitude of the crest of that wave in the wells farther downstream. These hydrographs illustrate that the observed fluctuations are not all uniform and consistent; irregular heights and times are observed in the ground water at some wells within the bank-storage zone.

ESTIMATE OF THE MAGNITUDE OF THE BANK STORAGE

In the 100 square miles of the zone of observed bank-storage effect (fig. 2), the average observed fluctuation in water level is 9.4 feet, and the average effective porosity is 0.14. The volume of water in bank storage may be computed as follows:

$$V_s = Ahp$$

where:

V_s = volume of water in storage,
A = area of the zone of observed bank-storage effect,
h = average range of water-level fluctuations, and
p = average effective porosity of material newly saturated or drained

$$V_s = (100 \times 640) \times (9.4) \times (0.14)$$

$$V_s = 84{,}000 \text{ acre-feet}$$

The assumption that the conditions on the left bank are equal would indicate that the bank storage between North Richland and the bedrock reaches of the river near Priest Rapids at the time of the average flood peak is about 170,000 acre-feet of water. However, this assumption is not entirely true because the glaciofluviatile and fluvial deposits lie at higher levels along much of the left bank.

The bank storage occupies the thin wedge between the inward-sloping preflood water table and the outward-sloping water table at the flood peak. For a river rise of 20 feet this bank storage should contain about 99 percent, or 168,000 acre-feet of water, contributed by the river and about 1 percent of ground water whose normal movement toward the river is temporarily halted. The writers consider both types of water to be bank storage. If the 168,000 acre-feet of water is prorated over the 45-day rise to flood peak, the average diminution of the river at Richland is about 3,700 acre-feet per day.

The actual average distance that the influent water penetrates the ground is much less than the width of the zone in which the water table rises. This actual penetration is in the range of hundreds of feet at a maximum. An approximate solution may be obtained for the question of how far from the river this 168,000 acre-feet of river water actually moves: The volume of water moving to bank storage may be divided by the area of the riverbed at the flow peak (taken as 50 miles long by 0.50 mile wide) divided by the effective porosity (0.14), and an average penetration of about 75 feet is indicated for the infiltrating water.

The seasonal low-water level in wells in this zone is reached 150 to 180 days after the annual high; consequently, on the receding stage bank storage may contribute an average of 1,000 acre-feet per day or about 500 cfs (cubic feet per second) to the flow of the river.

For comparison, the channel storage added by the flood rise in this same segment of the river can be estimated by assuming an average change in width from ¼ to ½ mile during the 20-foot rise to flood peak. The resulting estimate of 240,000 acre-feet of channel storage is about 1.5 times the estimate for bank storage resulting from the same average annual flood.

PROJECTION OF THE DERIVED VALUES ALONG THE MAIN STEM OF THE COLUMBIA RIVER

Upstream from China Bar, the natural channel of the Columbia River is on bedrock over much of its length to the Canadian border. The effective porosity and permeability of these rocks is less than that of the conglomerate member of the Ringold but is not known sufficiently to permit this type of an estimate of the bank storage. In places between China Bar and the Canadian border, glaciofluviatile and fluviatile deposits as well as glacial deposits and Recent alluvium are known to accept and discharge considerable bank storage; the bank storage may be large where these deposits border the river in reservoirs. The probability that water entered and withdrew from bank storage in amounts measurable at the gaging stations is indicated for certain years by a comparison of the discharge records at Bridgeport and Grand Coulee Dam, 165 and 220 river miles respectively, above China Bar. At the present time, however, estimates of bank storage at the Hanford Reservation would require at least large adaptive weighting to be applicable to other reaches of the main stem of the Columbia River.

In recent years water-management agencies have attributed to bank storage some of the apparent losses and gains of water in certain segments of the river during particular changes in the river flow or river level. The filling of reservoirs behind hydroelectric-power dams has at times taken more inflowing water than the carefully measured reservoirs were expected to hold. Likewise, the lowering of the level in some reservoirs has yielded more water than their surface storage would indicate. The necessity for integration of bank storage into river-management operations is evident.

SUMMARY

During the annual flood-runoff cycle, the Columbia River rises and falls about 20 to 30 feet, and the water level in wells along the river on the Hanford Reservation rises and falls in response to the changes

in the river stage. The observed annual rise in ground-water levels averages about 9.4 feet beneath a riverbank zone, which averages 10,000 feet in width and has an aggregate area of about 100 square miles on the right side of the Columbia River.

The rise and fall of the water table indicates that throughout the zone adjoining the right bank of the river, in the reach from the bedrock channel near China Bar to the head of McNary Reservoir near Richland, there may be stored and released annually about 85,000 acre-feet of water. About 99 percent of this water is believed to be diverted from the river and about 1 percent to be retarded ground water. A projection of this derivation to include the somewhat different left side of the river, with the storage averaged for a 45-day period of river rise, indicates that an average of about 3,700 acre-feet of water per day is diverted directly from the river to bank storage during the average 45-day rise of the river to flood peak. The water returns to the river at an average rate of about 1,000 acre-feet per day during the 165-day period of the river's decline.

The bank storage is equal to about two-thirds of the water placed in channel storage by the average annual rise to flood peak. In the future, bank storage may need to be derived systematically and its effects on streamflow integrated into the management of the water resources of many rivers.